March 19, 1896.

Sir JOSEPH LISTER, Bart., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "The Photographic Values of Moonlight and Starlight compared with the Light of a Standard Candle." By Captain W. DE W. ABNEY, C.B., R.E., F.R.S. Received March 3, 1896.

Estimations of the visual values of moonlight and starlight by several observers are extant, but, as might be expected, they vary considerably from each other, more particularly when they are referred to such a variable standard as sunlight. For instance, the light of the moon is said by Wollaston to be roughly $\frac{1}{800000}$ of that of the sun; by Bouguer, to be $\frac{1}{300000}$. Probably Zöllner's estimate is a fair one, he taking it as $\frac{1}{618000}$ that of sunlight. As far as I am aware, the photographic values of moonlight and starlight have not been recorded with any great precision, and I now offer some determinations which I have made under favourable circumstances, and referred them to the British standard candle, which, though occasionally showing variation in the light it emits, yet can be utilised when care is taken to check the results by a reference to a standard such as a Siemens amyl acetate lamp, which is extremely constant. My first recent attempt at measuring the value of moonlight was made at Chamounix in the early part of January, 1895. At that time the sky was cloudless, but on some few occasions there was a very slight mist in the valley which precluded any great degree of accuracy from being attained on those nights, and further, as I was obliged to leave for England before full moon, the observations I made there are necessarily incomplete so far as the object I had in view is concerned. I have thought it worth while to give two examples of these observations, however, to show how necessary it is that both sky and atmosphere should be perfectly clear from any mist or haze. I may state that when the observations were made there was about 45° (F.) of frost. The method of observation that was adopted was as follows:—A scale of graduated opacity was prepared on a photographic plate by

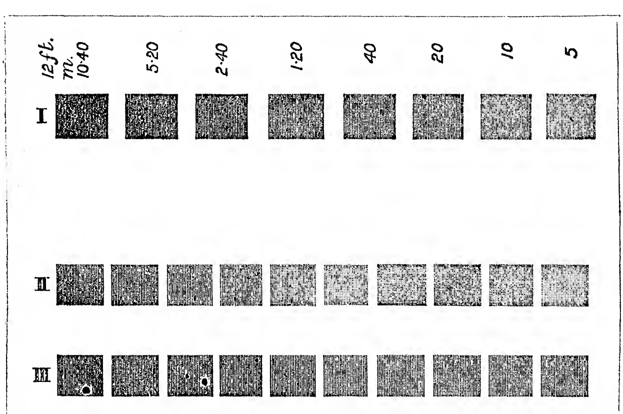
giving it varying lengths of exposure to a source of light on different small square areas of the plate; on development with the ferrous oxalate developer a scale of graduated opacities was obtained which were carefully measured by the method I have already described in my paper "On the Transmission of Sunlight through the Earth's Atmosphere" ('Phil. Trans.,' 1891). Visually, the measurements of this scale were very good as circumstantial evidence proved, but it remained to determine whether the silver opacities were more or less opaque to the rays used in photography than they were to the eye. Four scales of gradation had been made on the same plate, by giving exposures for the same time to four distinct squares of the plate, another exposure was made on another four distinct squares, and so on; so that eventually, on development, four complete scales of similar gradation were prepared—all being developed together. Each scale was measured and found to be practically the same. The four scales were then separated. Platinum paper was placed behind each, and they were severally placed accurately at such distances from the positive pole of the electric arc light that the illumination of the paper, after passing through a square of different density on each scale, should, according to the eye measurements, be the same. If the photographic and visual opacities were the same, then, on illuminating the four scales which, of course, were fixed normally to the line joining them and the carbon points, the amount of platinum black deposited, after treatment with oxalate of potash, should be the same on the part of papers covered by these squares whose transparency was being tested.

Several experiments carried out in this way showed conclusively that the opacities, visual and photographic, were the same. In no case was there a variation from the calculated opacity of 2 per cent. It may therefore be taken that the scale of gradation used in the moonlight and starlight measurements will allow intensities of photographic light to pass through in the same proportion that it does visual light. For convenience, the transparencies of the different squares of the scale were calculated out in powers of 2, for I have shown elsewhere that, by using intensities of light acting on a plate in a geometrical series for abscissæ, and making the measured transparencies the ordinates, a curve is produced which is, for a considerable distance, practically a straight line. For checking the results of measurement it thus becomes of great use. Moreover, this plan enables us to use a much greater range of exposure for diagrammatic purposes than is practicable if such range is expressed as an arithmetical scale. Hence its adoption for the experiments to be described.

It must be remembered that there are two ways of giving varying exposure to light, one by using a constant source of illumination, and varying the time of exposure, the other by exposing for a constant

time and altering the intensity of the light acting. Thus we may place an amyl acetate lamp or a candle 16 feet away from a sensitive surface, and expose different small portions of the plate for 2, 4, 8, 16, &c, seconds; or we may place the amyl acetate lamp at 1, 2, 4, 8, &c., feet away from the plate, and, after each move, expose a different portion of the plate for, say, 20 seconds. Up till recently it has been held that the resulting chemical action is the same in both instances, so long as the "time" × "intensity" is the same, so that an exposure to a light 10 feet away from the plate for 10 seconds effects the same chemical decomposition of the sensitive salt as an exposure of 1000 seconds when the lamp is placed 100 feet away. This I have shown in the 'Proceedings of the Royal Society,' and in the 'Photographic' and 'Camera Club' Journals, to be wide of the mark if the sensitive surfaces are what we may call slow, though it is practically the case when using rapid plates. (It should be remarked that for printing-out processes this variation has not so far been found.) This was a point to which my attention was necessarily directed, and the readiest means of proving if the plates to be employed were suitable, was not only to expose through the scale of opacities, but subsequently to impress on the same plate a scale obtained by exposures to a fixed source of light but with varying times. If when plotted the two curves were identical or parallel, the proof was sufficient to show that the plates might be safely employed without any error creeping in. For it may be remarked that the straight part in what we may call the "intensity" curve is, in a slow plate, always less steep than in the time curve. With the plates that were used the "time" and "intensity" curves were found to fulfil the condition of parallelism.

Fig. 1.



The accompanying figure is from a photograph of an exposure to moonlight and candlelight through the scale of opacities, and of a "time" scale made with an amyl acetate lamp. This will indicate the method which was adopted better than a verbal explanation.

I is the time scale, the exposures being made to an amyl acetate lamp at a convenient distance.

II is the exposure to candlelight through a graduated scale.

III is exposure to moonlight through the same graduated scale.

10.5 P.M., *January* 3, 1895.

Plate exposed to moonlight for 90 *seconds through the graduated opacity scale; another part to the light of a paraffin candle at* 5 *feet for* 60 *seconds.*

(In both cases the light fell normally on the plate.) The moon's altitude during the exposure was only about 16°; the light had, therefore, to pass through 3·6 atmospheres.

Intensity of light transmitted through the scale in powers of 2.	Transparencies of photographed scale due to	
	Moonlight.	Candlelight.
1·45	100	86
1·75	100	82
2·20	100	74
2·7	98	65
3·3	92	55
4·0	85	42
4·8	71	30
5·8	53	20·5
6·3	43	17
6·55	39	16

Diagram 2 shows these figures plotted graphically. The distance apart of the two curves is 2·3, that is, the light of the moon on this occasion was $2^{2\cdot 3} = 4\cdot 95$ times less photographically bright than that of a candle at 5 feet distance, or was equal to one *standard* candle at very nearly 10 feet, or closely 0·01 standard candle at 1 foot distance. As the exposure to the candlelight was only two-thirds of that to the moon, this result must be reduced accordingly. On this occasion there was a slight ground haze; the low results are due largely to the atmospheric absorption.

The results have been given in standard candles (which we will in future designate as S.C.). The value of the paraffin candle employed was compared photographically by employing each to

furnish a "time" scale on the same plate. Their visual illuminating power was first of all compared, and at the distances where they balanced one another, the exposure to the plate was given.

The paraffin candle employed was found to be 1·085 of the standard candle. The exposures were given to the plate at 10 feet and 9·6 feet respectively.

The following table gives the results:—

Exposure given, in seconds.	Standard candle at 9 ft. 6 in.	Paraffin candle at 10 ft.
20	79·0	71·0
40	51·5	46·0
80	32·5	29·5
160	19·0	21·5

When the curves are plotted, it will be found that they are at such a distance apart that the light of the paraffin candle is photographically 1·21 times more luminous than that of the standard candle, though visually they had the same illuminating value on the screen. All results obtained with the paraffin candle have therefore to be increased in that proportion to bring them into the values of standard candles.

7 P.M., *January* 4, 1895.

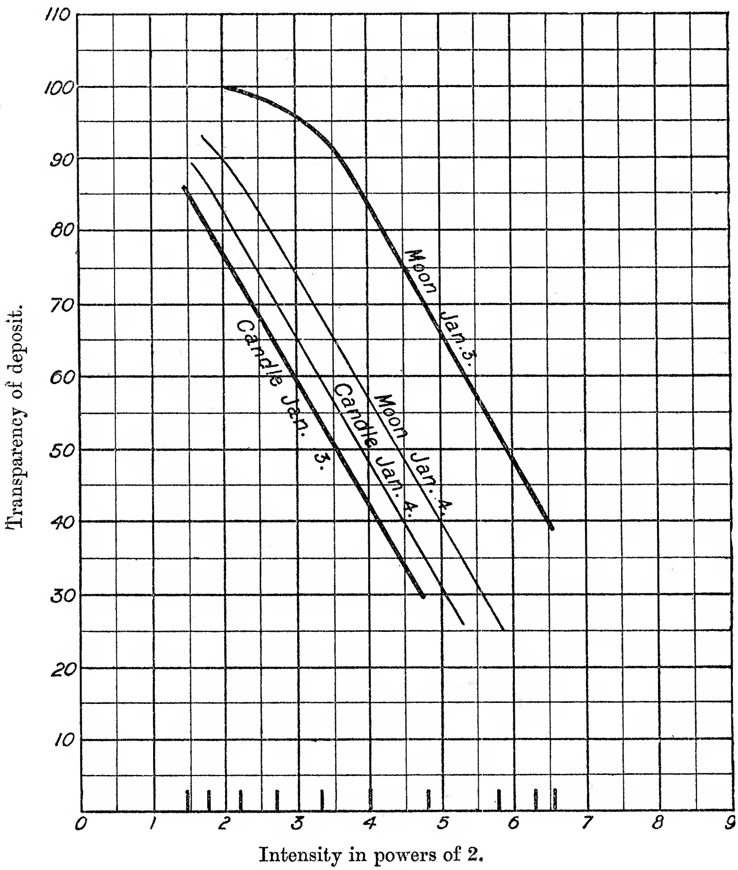
Plate exposed to moonlight through the graduated opacity scale for 60 *seconds; another part to the light of a paraffin candle at* 5 *feet for* 60 *seconds.*

(As before, the light fell normally on the surface of the plate.) The moon had during exposure an altitude of about 50°; the light had, therefore, to traverse about 1·3 atmospheres.

Intensity of light transmitted, in powers of 2.	Transparencies of photographed scale due to	
	Moonlight.	Candlelight.
1·45	93·5	92
1·75	92·0	87
2·20	87·0	80
2·70	80·0	70
3·30	69·0	60
4·00	56·0	49
4·80	42·5	35
5·80	25·5	22
6·30	20·5	16
6·55	19·0	15

Diagram 2 shows the curves plotted from the above table, and from it is derived the distance apart of the parallel curves, which is 0·47, that is, the light of the moon on this occasion is $2^{0.47} = 1{\cdot}38$ times less photographically bright than the candle at 5 feet from the plate. The moon was therefore equal to 0·725 candle at 5 feet, or

DIAGRAM 2.



to one *standard* candle at 5·32 feet, or to 0·035 standard candle at 1 foot distant from the plate. The moon was almost exactly at its first quarter. If the light of the full moon were only double, then the value would be 0·07 standard candle at 1 foot distance.

Not having an opportunity to make a measurement of the light at full moon at Chamounix, the investigation was continued in England. In February the weather was intensely cold, and the nights were

remarkably free from haze. The moon was full on February 9 at 5.23 P.M. An exposure was made on February 8 at 7.30 P.M. at South Kensington, and another at 10.5 P.M. on February 9, near Wimbledon, away from buildings of any importance. These two localities were chosen to see if the country gave results differing from those obtained in town. At 7.30 on February 8 the altitude of the moon was 35°, so that the light had 1·7 atmospheres to traverse. At 10.5 P.M. in Wimbledon it had an altitude of 43°, so the light had to traverse but 1·45 atmospheres.

The results arrived at show that the night at Wimbledon on this particular occasion was clearer than at Kensington, even allowing for the absorption of the atmosphere. In my paper "On the Transmission of Sunlight through the Earth's Atmosphere," it was shown that the exponential coefficient of absorption in the clearest atmosphere was 0·340 for the rays affecting the silver salt employed, and adopting this it will be seen that there must have been a greater haze in London than at Wimbledon. That this is not always the case is shown that in measurements of starlight the two give identical results on the same night.

7.30 P.M., *February* 8, 1895.

Plate exposed to moonlight for 60 *seconds through the graduated opacity scale, and another part of the same plate to a paraffin candle at* 5 *feet distance for* 60 *seconds.*

Intensity of the light transmitted through the scale in powers of 2.	Transparencies of the photographed scale due to	
	Moonlight.	Candlelight.
1·45	93·0	100·0
1·75	84·0	100·0
2·20	74·0	97·0
2·70	64·0	88·0
3·30	49·0	74·0
4·00	35·0	60·0
4·80	22·5	41·5
5·80	13·2	24·5
6·30	10·0	18·0
6·55	9·0	15·0

Plotting these curves, as shown in Diagram 2, we find that their distance apart is 1·1; that is, the light of the moon is $2^{1\cdot1}$ = 2·4 times brighter than the candle at 5 feet. Moonlight was therefore equal to 2·9 standard candles at 5 feet, or equal to 1 S.C. at 2·94 feet; that is, moonlight was equal to 0·116 S.C. at 1 foot.

10.5 P.M., *February* 9, 1895.

Plate exposed to moonlight for 60 *seconds through the graduated opacity scale, another part of the same plate was exposed to the light of a paraffin candle for* 60 *seconds at* 7 *feet distance.*

Intensity of light transmitted through the scale of opacity, in powers of 2.	Transparencies of photographed scale due to	
	Moonlight.	Candlelight.
1·45	48·0	100·0
1·75	42·0	99·0
2·20	31·0	96·0
2·70	24·0	91·0
3·30	16·5	75·0
4·00	12·7	62·0
4·80	7·9	42·0
5·80	5·4	23·5
6·30	4·0	17·0
6·55	3·8	14·5

Plotting these curves as before, we find that they are 3·1 apart; that is, that moonlight is $2^{3.1} = 10{\cdot}7$ times more intense than the candle at 7 feet. Moonlight was therefore equal to 1 S.C. at 1·94 feet, or was equal to 0·266 S.C. at 1 foot. We thus find that the moon at the full is equal to 0·266 S.C. in its action on a bromide plate. In the paper already referred to it was shown that when measuring different intensities on a plate, the integral increase in effect of white light increases in the same ratio as does the intensity of a part of the spectrum whose wave-length is at the maximum part of the curve of sensitiveness. With these plates the point of maximum sensitiveness is about λ 4450.

Taking Zöllner's visual measure of moonlight, he found it to be about 0·012 candle at 1 foot. Sunlight, reduced in brightness to visual equality, I have found on a bright, clear day in summer, near midday, to have a photographic value 28·5 times greater than that of an amyl acetate lamp flame, and that a standard candle of equal visual intensity has a photographic intensity of 1·1 times that of an amyl acetate flame. This makes sunlight to have a photographic intensity, the visual intensities being equal, of very nearly 26 times that of a standard candle. As moonlight is reflected sunlight, it may be presumed that the two have the same quality. If this be so, we should arrive at moonlight, being 0·01 visually of a standard candle, the moon being at the full, a value which is near that given above. This mode of comparison must necessarily be only approximate, on account of the variable nature of sunlight, and therefore of moonlight.

It may be asked whether there are good grounds for presuming that the standard candle was emitting the same amount of light on the occasions quoted. There can be little doubt that it was, as on every plate was impressed a "time" scale by exposure to an amyl-acetate lamp. A comparison of this with the scale given by exposure to the candle showed that any variation was negligible.

We next have to consider the photographic value of total starlight. It appeared to me that the fairest way of arriving at it would be to expose a plate through the graduated scale to the action of the light in a horizontal position. This would practically be the illumination of a piece of white paper laid in that position. The great point was to get a clear horizon, or at all events an horizon which was not obstructed to any great extent by any adjacent tree or building. The top of South Kensington Museum answers to the necessary conditions, as it is higher than any close building, except the Natural History Museum towers, and these are at a considerable distance. At Wimbledon also it was possible to expose a plate with advantage, though the horizon was not absolutely clear from the spot which was available. Exposures were made at both places, and the highest value at South Kensington agreed with the highest value at Wimbledon; it is therefore unnecessary to give the latter. It should be noted that it is a decided advantage to have more than one graduated scale bearing identical opacities, as it enables simultaneous exposures to be given at different localities.

The results of two exposures will be given, as the others do not differ widely from them.

January 25 *and* 26, 1896.

Exposure to sky from 11.30 P.M. *on January* 25 *to* 1 A.M. *on January* 26, *being* 1 *hour and* 30 *minutes. The exposure to candlelight was for* 60 *seconds at* 10 *feet distance.*

Intensity of light through the graduated scale in powers of 2.	Transparencies of photographed scale due to	
	Starlight.	Candlelight.
1·45	66·5	100·0
1·75	62·0	100·0
2·20	53·0	100·0
2·70	42·0	100·0
3·30	31·0	94·0
4·00	23·0	84·0
4·80	16·5	69·0
5·80	13·0	49·5
6·30	11·0	41·0
6·55	10·0	35·0

Plotting these curves as before, it is found that their distance apart is 3·5, that is, the light of the stars is $2^{3.5} = 11{\cdot}2$ times more photographic than the candle at 10 feet off. As the exposure was 90 times more prolonged in the first case, this means that the light is only 11·2/90 or 0·125 that of a candle at 10 feet, that is, it is equal to one standard candle at 25·7 feet distance, or that it is equal to 0·001515 candle (S.C.) at 1 foot.

January 29, 1895.

The exposure to starlight lasted from 10.15 *to* 10.45, *or* 30 *minutes. The exposure to candlelight was for* 60 *seconds at a distance of* 7 *feet.*

Intensity of light through the graduated scale, in powers of 2.	Transparencies of the photographed scale due to	
	Starlight.	Candlelight.
1·45	99·0	99·0
1·75	98·0	98·0
2·20	94·5	95·0
2·70	82·5	83·0
3·3	70·5	71·0
4·0	55·5	55·5
4·8	34·5	35·0
5·8	18·5	18·0
6·3	13·7	14·0
6·55	11·5	11·5

These two curves are practically identical, hence we may take it that on this night exposure to starlight for 30 minutes was equal to exposure to the candle for 1 minute at a distance of 7 feet, that is, starlight is equal to one S.C. at 34·8 feet, or to 0·000825 candle (S.C) at 1 foot. The variation may be due to two causes—(1) the state of the atmosphere, or (2) to the difference in heavens; the first is most probable. It may be interesting to know that photographic transparencies from negatives were made by contact during these exposures of the scale. In all cases there was evidence of considerable over-exposure in the starlight.

It has been stated that in order to ascertain that the candle was giving the normal illumination for the observations by moonlight, comparisons of its light were made with a standard amyl acetate lamp. This comparison was also made on these occasions.

We may now compare the light of the full moon with that of the stars. Fig. 3 gives a map of the stars with the planets Jupiter, Mars, and Neptune shown in position for the last exposure. The

positions on the first night differ so little from it that it is unnecessary to repeat the chart. I have to thank the Astronomer Royal for these charts, he kindly having had them prepared for me from Phillips' atlas. I have, however, reduced them from the elliptical form to that of a circular disc.

FIG. 3.

The light from Jupiter has been estimated, and it would not be far wrong to assume that it is equivalent to a candle placed at 800 feet from the screen. It may, therefore, be neglected in taking into account the light from the stars, and much more so may Mars and Neptune. It must be recollected that the exposure was made to the plate in a horizontal position. If the stars were uniformly distributed in the hemisphere the measured light would be but half of the actual light, since it would strike the plate at an angle, except at the zenith. Besides this, however, we have to take into account the atmospheric absorption, and taking the most favourable coefficient for the plates used we shall find that only about 25 per cent. of uniformly distributed starlight would be effective. Total starlight would thus be $4 \times 0{\cdot}001515$ or $0{\cdot}006$ standard candle at 1 foot distant from the screen. Taking moonlight as $0{\cdot}266$ of a standard candle, we find

that moonlight is 44 times brighter than starlight when unabsorbed by more than 1 atmosphere, and if uniformly distributed, though, for illumination of a horizontal screen, it is 175 times brighter so far as photographic action is concerned. If we take the visual quality of the two lights to be the same, these figures should bear the same proportion for visual observation. If moonlight be 0·01 candle at 1 foot distance, starlight will be 0·000057 candle at the same distance, that is, the visual value of one candle at nearly 132 feet distant from a screen. With an intensity of about 6/1000000 of candle placed at 1 foot from a screen, or about 10 times less illumination than the above, the screen would be invisible. It follows that the actual illumination given by starlight will be less than that stated.

Addendum. March 25, 1896.

I ought to have drawn attention to the fact that though the above comparison of moonlight with starlight was taken from actual observations, it would not have been unfair to have deduced the value of moonlight as observed at Wimbledon with the moon in the zenith. From the observations made and recorded in my paper on the "Transmission of Sunlight through the Earth's Atmosphere," the coefficient of absorption μ for the rays affecting the bromo-iodide of silver can be shown to be 0·340, under the very favourable circumstances under which the exposures were given. As the rays of the moon had to traverse 1·45 atmosphere, and then showed a photographic illuminating power of 0·266 S.C.; had they only had to traverse a thickness of 1 atmosphere, this number would have been 0·308 S.C. This last value would have been equivalent to a visual estimation of moonlight of closely 0·012 S.C. at 1 foot. Starlight would have then been rather more than 200 times less bright than the light of the full moon.

II. "Helium, a Gaseous Constituent of certain Minerals. Part II—Density." By WILLIAM RAMSAY, F.R.S., Professor of Chemistry in University College, London. Received March 12, 1896.

§ 1. In the original notice of this gas ('Proc. Roy. Soc.,' vol. 58, p. 81), it was stated that the gas obtained from clèveite contained some, but not much, nitrogen, and no hydrogen. I have since prepared samples from bröggerite, samarskite, and fergusonite, and I find that in all cases the gas evolved on heating the mineral in a vacuum is rich in hydrogen; the amount of nitrogen is in all cases

FIG. 1.

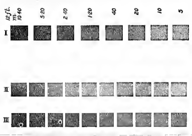


FIG. 3.